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INSTRUMENT AND TREE-RING BASED ESTIMATES OF THE ANTARCTIC OSCILLATION INDEX

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1. INTRODUCTION

Detection of climatic changes during the last century, and their potential attribution to increasing concentrations of atmospheric greenhouse gases and other anthropogenic activities, require a realistic estimation of the level of natural climate variability on decadal and longer timescales. To extend climate records before the period of observational data, palaeoclimate proxy data are used. Proxy and long instrumental data have been used to provide reconstructions of atmospheric circulation modes such as the North Atlantic Oscillation (e.g. Cook et al. 2002). However, to our knowledge no reconstruction exists for the Antarctic Oscillation (AAO),

The AAO, the dominant mode of Southern Hemisphere (SH) extratropical circulation, which has also been termed the Southern Annular Mode (Thompson and Wallace 2000), is a zonally symmetric mode representing exchange of mass between the midlatitudes near 45^{O}S and high latitudes poleward of 60^{O}S. It characterises fluctuations in the strength of the circumpolar vortex. This mode has been found to be present at various atmospheric levels, e.g. SLP and 500hPa (e.g. Rogers and van Loon 1982), and 850hPa (e.g. Thompson and Wallace 2000).

This paper provides a brief overview of results presented in Jones and Widmann (2002) (hereafter JW), with an estimate of the strength of the Austral Summer Antarctic Oscillation using station sea level pressure records for the period 1878-2000, the first to our knowledge. The reconstruction was obtained by relating the Antarctic Oscillation Index (AAOI) derived from NCEP/NCAR reanalysis data to the leading principal components of station records using multiple regression analysis.

To extend this record further back, a second reconstruction using tree-ring chronologies back to 1743 has also been undertaken. Comparison with the station-based reconstruction shows moderate agreement on interannual and decadal timescales, but the comparison also points towards the inherent uncertainties of proxy-based climate reconstructions. In particular it was found that this tree-based reconstruction may have been influenced by a warming that is not related to changes in the AAOI during the twentieth century. Comparison of the tree-based reconstruction with a published reconstruction of zonal flow over New Zealand before the 20th century shows common features.

2. DATA AND METHODS

For model fitting we define the AAOI as the first PC of detrended NCEP/NCAR NDJ SLP for the domain 20^{O}S-60^{O}S, and the AAO pattern as the first EOF of these data for the period 1948-1985 (the period of chronology and NCEP overlap). The SLP data were first regridded to a 5^{O} x 5^{O} grid. The southern limit of the analysis domain was chosen to be 60^{O}S, to exclude the region of strongest possible spurious trends identified by Hines et al. (2000). The detrending of the NCEP data also ensures that neither the structure of our AAO pattern nor the statistical relation of its amplitude to the predictor variables is contaminated by potential unrealistic trends in the NCEP data.

SH station SLP records were obtained from Phil Jones, Climatic Research Unit, UK (Jones 1991), from these, 28 stations, those with data since at least 1878, were used. To select those containing an AAO signal, the stations were correlated with the AAOI, and those that were significant at the 5% level retained (Fig. 1).

Tree-ring width chronologies from Argentina, Chile, New Zealand and Tasmania were obtained from the International Tree Ring Data Bank, and restandardised by Connie Woodhouse using a cubic spline. Autoregressive modelling was used to remove autocorrelation from the standardised series (see JW for further details). Chronologies were retained that were significantly correlated with the AAOI (nine from a total of ninety, Fig. 2).

Multiple linear regression was used to estimate the AAOI from the leading PCs of normalised tree-ring records or station observations, so-called principal component regression (PCR). Our normalisation is such that the variance of the AAOI obtained from the detrended NCEP seasonal means equals one for the period 1948-1985. The physical units are associated with the AAO pattern. Local SLP signals associated with a given AAOI can be obtained by multiplying the local AAO pattern loading with the AAOI. The predictor PCs are derived from NDJ seasonal means of station SLP or annually resolved tree-ring width chronologies (both standardised to unit variance; detrended for fitting, trend included for reconstruction). The weights for the normalised station or tree-ring records were obtained by multiplying the PC weights by the EOF loadings and summing over the leading EOFs. (Figs 1 and 2). For independent validation of the reconstruction we did not want to withhold more than a few years. Instead we use a cross validation procedure, whereby we performed the PCR 37 times, each time estimating a different year not included in the fitting data. These 37

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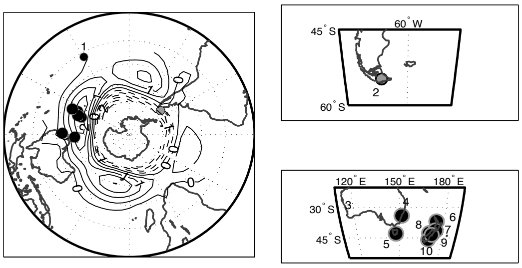
individual years were then concatenated to produce a validation record (see JW for further details).



1 = Tahiti (–45.9, –149.6)
2 = Ushuaia (–54.8, –68.0)
3 = Perth (–31.9, 116.0)
4 = Sydney (–33.9, 151.2)
5 = Hobart (–42.9, 147.3)
6 = Auckland (–36.9, 174.8)
7 = Wellington (–41.3, 174.8)
8 = Hokitika (–42.7, 171.0)
9 = Christchurch (–43.5, 172.6)
10 = Dunedin (–45.9, 170.5)

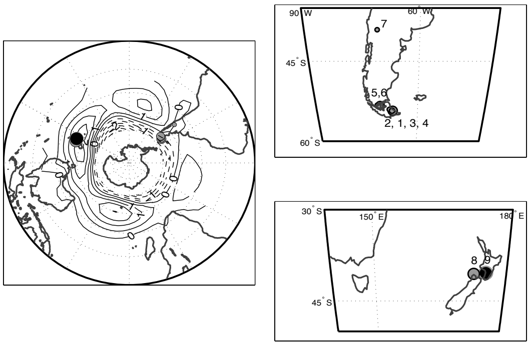
Fig. 1. The Antarctic Oscillation pattern defined as the first EOF of detrended NCEP SLP and the station regression weights for normalised station SLP used to produce the Antarctic Oscillation Index reconstruction. Isolines are in hPa and show the pressure changes for Antarctic Oscillation Index = +1. The regression weights are dimensionless. The grey filled circles denote negative values, the black filled circles positive values. The circle area is proportional to magnitude. The station coordinates are in brackets.

3. RESULTS

3.1 The station-based reconstruction.

The AAO pattern and the station weights used to obtain the station-based reconstruction (SBR) are shown in Fig. 1. The AAO pattern explains 28% of the variance of the detrended data and is characterised by opposite signs at mid and high latitudes. In the positive phase of the AAO the westerly flow at high latitudes is strengthened and that at midlatitudes weakened, and in the negative phase this is reversed. The coefficient of multiple determination during the fitting period is 0.92, thus 85% of the variance of the detrended NDJ AAOI can be explained by the PCR model. The correlation between the reconstructed AAOI and the detrended NCEP AAOI in the validation period is 0.91. The reduction of error (RE) in the validation period is 0.82, which also indicates good prediction skill. Station data for the period 1985-2000 were not used for model fitting, thus can be compared to the NCEP AAOI used for an independent model evaluation. The correlation between these series is 0.69. The SBR is shown in Fig. 3, where it can be seen that the SBR shows a period of dominantly negative AAOI from around 1900 up to the late 1950s, then a period of more positive values during the 1960s, followed by a trend to negative values until 1980, and then again to positive values until the end of the record.

The confidence intervals assume that the uncertainty remains constant back in time. However there is the possibility that the relationships derived during the calibration period may not remain constant throughout the reconstruction, particularly because the SBR is based predominantly on information from one AAOI centre of action.



1 = Estancia Carmen Camino (–54.26, 67.55)
2 = Estancia san Justo (–54.03, –68.34)
3 = Lago Yehuin (–54.28, –67.43)
4 = Estancia Maria Cristina–Bosque Virgen (–54.30, 67.05)
5 = Monte Grande Magallanes (–53.12, –72.10)
6 = Peninsula Brunswick (–53.3, –71.10)
7 = Norquino (–39.07, –71.07)
8 = Moa Park (–40.56, 172.56)
9 = Putara (–40.40, 175.31)

Fig. 2. The AAO pattern (as in Figure 1) and the tree regression weights for normalised tree-ring chronologies. Isolines as in Figure 1. Circles as in Figure 1.

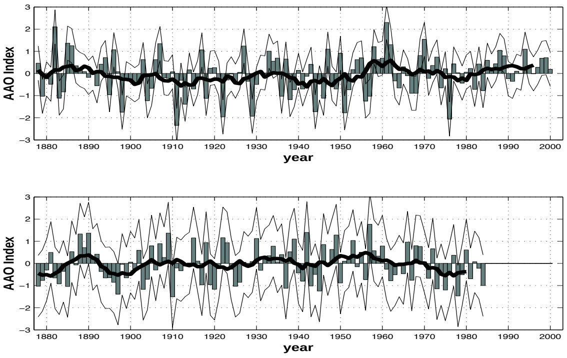


Fig. 3. The reconstructed AAOI. Bars show the station-based reconstruction (SBR) (top) and the tree-based reconstruction (TBR) (bottom). The solid black line is the nine year running mean. The thin lines show the 95% confidence intervals derived from residuals in the fitting period. The years are dated by the November/December.

3.2. The tree-based reconstruction

The AAO pattern and the tree-ring weights used to obtain the tree-based reconstruction (TBR) are shown in Fig. 1. The coefficient of multiple determination during the fitting period is 0.72 (52% AAOI variance explained by the regression model). The TBR is shown in Figures 3 and 4. The correlation between the reconstructed AAOI and the detrended NCEP AAOI in the validation period is 0.66. It is shown in JW that these relationships are physically plausible. As the SBR has considerable skill, we can validate the TBR against the SBR. The correlations between the SBR and TBR are encouraging, 0.43 for the period 1878-1985, 0.50 since 1900 and 0.56 for the fitting period (all significant at the 1% level). Although the significance of the correlations shows that the SBR and TBR are clearly related, their relatively low values reflect the substantial differences between the two reconstructions. Despite these differences, the SBR and TBR can be regarded as consistent, because their 95% confidence intervals overlap for all but four timesteps. The low-frequency variability, as represented by the nine year running mean shows some common features, although the correlation over the whole period is only 0.26, and 0.38 for the fitting period. The minima at around 1900 and 1940-50 are present in both reconstructions, as is the peak between 1930 and 1940 and the trend from positive to negative index between 1960 and 1980. The main difference is that the TBR shows a positive trend from 1900 to the late 1950s. This upward trend is less evident in the SBR, where the period from 1900 until the mid 1950s is dominated by negative values, followed by a period of positive index for five years, before a return to more negative values (Fig. 3)

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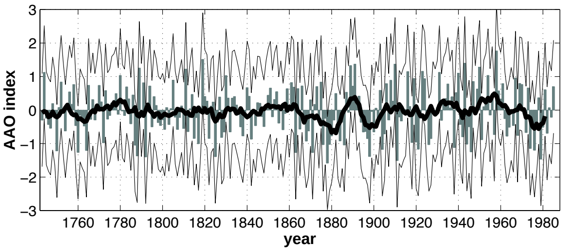

Fig. 4. The TBR. The solid black line is a nine year running mean. The thin lines show the 95% confidence interval. The years are dated by the November/December.

The linear trends over the period 1900-1960 are 0.008 yr-1 for the TBR and 0.003 yr-1 for the SBR. This difference can possibly be explained by the observed increase in New Zealand temperatures since the beginning of the 20th century, the rate of which reduced during the 1970s (Folland and Salinger 1995). The New Zealand chronologies, Moa Park and Putara, have negative (positive) responses to temperature respectively (D'Arrigo et al 1998, Xiong and Palmer 2000). The regression weights are positive and negative for the former and latter respectively. Thus a temperature increase over New Zealand would result in an increased reconstructed AAOI. We suggest that the temperature-sensitive New Zealand trees may be responding to a local temperature increase that is unrelated to the AAOI, leading to a positive trend in the TBR. However, because this trend in the TBR is small, and not significant, this hypothesis is tentative. If we take into account the confidence intervals of the reconstruction, other trends may be possible

Validation of the TBR prior to the SBR period can be achieved through comparison with other proxy reconstructions. Support for the TBR before the late 19th century is given through moderate agreement with the New Zealand zonal flow reconstruction of Salinger et al. (1994), although this reconstruction was also produced from temperature (and precipitation) sensitive chronologies and therefore may also be affected by temperature changes that are not induced by the reconstructed circulation. There is also some agreement between the SBR and the trans-polar index reconstruction of Villalba et al. (1997).

4. CONCLUSIONS

The SBR can be regarded as relatively reliable, because of the high coefficient of multiple determination in the fitting period and the high coefficient of multiple determination and the high reduction of error during the validation period. The TBR should be regarded as a first estimate for the pre-instrumental AAOI, the optimal given the data available. The uncertainties are clearly too high to draw definite conclusions on climate variability during the pre-instrumental period.

The temperature and precipitation signals of the Antarctic Oscillation have been calculated (JW) and show that the response of the chronologies to Antarctic Oscillation variability is physically-plausible. In addition it was shown (JW) that a substantial fraction of the observed warming over much of Antarctica between the late 1950s and the 1980s can be linked to changes in the AAOI, whereas the observed warming over New Zealand since the 1950s are not linked to the AAOI.

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